LEARNING FROM ACCIDENTS IN AVIATION BY APPLYING HUMAN FACTORS ANALYSIS AND CLASSIFICATION SYSTEM (HFACS)

Wen-Chin Li[1], Tony Head[1], Chung-San Yu[2], Syu-Yi Chen[3], & Fuh-Eau Wu[4]
Cranfield University, U.K. [1], Air Force Academy, R.O.C. [2], Fooying University, R.O.C.[3],
Cheng-Shiu Institute of Technology, R.O.C. [4]

Human error is systematically connected to features of instruments and to tasks of the operators, and, as been recognized more recently, their operational and organizational environment. The purpose of this study was to assess the utility of the Human Factors Analysis and Classification System (HFACS) framework as an accident investigation tool in the R.O.C. Air Force. In addition, the classification of data using HFACS highlighted several critical safety issues in need of further intervention research. Based upon Reason's (1990) model of latent and active failures, HFACS addresses human error in the aviation system including four levels of failure: (1) unsafe acts of operators, (2) preconditions for unsafe acts, (3) unsafe supervision, and (4) organizational influences. The results demonstrate that the HFACS framework can also be a viable tool for use within the R.O.C. Air Force.

Introduction

To improve flight safety, R.O.C. Air Force Headquarters investigates the pattern of mishaps annually. The findings are that military aviation accidents attributable solely to mechanical failure have decreased markedly over the past 25 years, but those attributable to human error have declined at a much slower rate and remain the primary cause of between 60 and 70 percent of all accidents.

In recent years, the focus on human error in aviation has shifted away from skill deficiencies and has identified decision-making, knowledge and attitudinal problems as the primary factors (Diehl, 1991; Jensen, 1997 & Klein, 2000). These decision-making, knowledge and attitudinal factors have been grounded under the concept known as Aeronautical Decision-making (ADM) and Cockpit/Crew Resource Management (CRM). By identifying that few pilot errors were the result of skill deficiencies, crew resource management has helped the entire flight operations focus on knowledge and attitude as the most promising areas for pilot performance improvements by making the most appropriate decisions for different situations.

Human error is a topic that researchers and academics in the fields of human factors and applied psychology have struggled with for decades. Indeed, there are a number of perspectives on human error, each of which is characterized by a common set of assumptions about the nature and underlying causes of errors. Unfortunately most error models and frameworks tend to be theoretical and academic, making them of little benefit to the applied needs of pilots (Wiegmann & Shappell, 2003). What is needed is a framework around which a need-based and data-driven safety programs can be developed.

Literature Review

According to the social psychological perspective, flight operations are viewed as social interactions among pilots, air traffic controllers, dispatchers, ground crew, maintenance staff, and commanders. Pilots' performance is directly influenced by the nature of the interactions among group members (Helmrich & Foushee, 1993). These interactions are influenced not only by the operating environment but also by both the attitudes and management of the individuals within each group. The major theme of social psychological models is that errors and accidents occur when there is a breakdown in group dynamics and interpersonal communications.

Diehl (1989) found that accidents, especially those involving human errors, are normally associated with a chain of events, a series of problems that degrade the performance of the equipment, the pilot, or both, until the accidents are inevitable. It is also axiomatic that it is usually easier to 'find' a problem than to 'fix' it. However, there were four basic kinds of accident prevention measures: (1) eliminate hazards and risks, (2) incorporate safety features, (3) provide warning devices, and (4) establish procedural safeguards.

Dekker (2002) argued that error has its roots in the system surrounding it, connecting systematically to mechanical, programmed, paper-based, procedural, organizational and other aspects to such an extent that the contributions from system and human begin to blur. The question of human or system failure demonstrates an oversimplified belief in the roots of failure. And it only very thinly disguises the 'bad apple' theory: the system is basically safe, but it contains unreliable components. These components are either human or mechanical, and if one of them fails, a mishap occurs. The point of a human error investigation is to understand why the decision and action that made sense to pilot at that time is deemed to be questionable by investigators.

Feggetter (1991) suggested that the aim of psychologists who investigate an accident is to collect and make a detailed examination of the large amounts of information available in the hope of gaining a complete understanding of the circumstances surrounding a particular accident. Hence by examining and correlating information across a number of accidents, predictors may be identified which may then be applied to individual crews or situations in order to ascertain the potential liability towards an accidents.

Wiegmann & Shappell (2001) pointed out that many accidents have their roots high within the organization, and it is the decisions made by those at the top that often influence the middle level of supervisors, as they oversee the day-to-day operations of the organization. Ultimately, it is the operators who inherit all of the responsibility of the organization. Unfortunately, when the system breaks down and errors occur, accidents and incidents to the operators are the end result. Reason's seminal work revolutionized the way that we view the human causes of aviation accidents, but it did not provide the level of detail necessary to apply solutions in the real world. Therefore, drawing upon Reason's (1990) original work of latent and active failures, the Human Factors Analysis and Classification System (HFACS) (Wiegmann & Shappell, 1995) was developed to fill that need.

The Human Factors Analysis and Classification System (HFACS) is a general human error framework originally developed and tested within the U.S. military as a tool for investigating and analyzing the human causes of aviation accidents. HFACS address human error at all levels of the system, specifically HFACS describes human error at each of four levels of failure from bottom to the top: (1) unsafe acts of operators (aircrew), (2) preconditions for unsafe acts, (3) unsafe supervision, and (4) organizational influences, each one affecting the next level. The HFACS framework bridges the gap between theory and practice by providing safety professionals with a theoretically based tool for identifying and classifying the human causes of aviation accidents. Because the system focuses on both latent and active failures and their inter-relationships, it facilitates the identification of the underlying causes of human error. To date, HFACS has been shown to be useful within the context of military aviation, as both a data analysis framework and an accident investigation tool (Shappell & Wiegmann, 2001).

Method

Data: The data of flight accidents were obtained from R.O.C. Air Force between 1978 and 2002, and a total of 519 accidents happened within those 25 years. The data were examined to determine the extent to which each HFACS causal category contributed to the accident. To avoid over-rating by any single accident, each causal category was counted a maximum of one time. In this way, the count acted as an indicator of the absence (0) or presence (1) of a particular HFACS causal category for a given accident.

Demographical variable

This investigation is aimed at analyzing each accident based on the following variable (1) flight missions including air combat maneuver, surface attack, night/Instrument flight, transition, test flight, air combat tactics, formation, solo flight and Others, (2) phase, including Taxi before Take-off, Take-off, Climb-out, Cruise/Operational Area, Descending, Approaching, Landing and Taxi after Landing, (3) ranks, including cadet, lieutenant, captain, major, Lt/colonel, colonel, and general, (4) types of aircraft, (5) wings and (6) accident categories including level-A, level-B as well as level-C accidents.

Classification Framework

The HFACS framework describes 18 causal categories within Reason's four levels of human failures (Shappell & Wiegmann, 1997). The first level of HFACS describes those unsafe acts of operators that can lead to an accident. The unsafe acts of operators including (1) decision errors, (2) skill-based errors, (3) perceptual errors and (4) violations. The second level of HFACS is preconditions of unsafe acts including (5) physical environment, (6) technological environment, (7) adverse mental states, (8) adverse physiological states, (9) physical/mental limitations, (10) crew resource management, and (11) personal readiness. The third level of HFACS is unsafe supervision including (12) inadequate supervision, (13) planned inappropriate operation, (14) failure to correct problem, and (15) supervisory violation. The fourth level of HFACS is organizational influences including (16) resource management, (17) organizational climate, and (18) organizational process (Wiegmann & Shappell, 2001).

Statistical analysis

This investigation applied frequency of occurrence, percentage and Chi-square. Chi-square tests are used to provide empirical evidence for theoretical models. They are based on the comparison of observed frequencies against expected (i.e. those expected by chance) frequencies.

Result

The overall analysis of 519 accidents associated with 1714 human errors causal factors by applying HFACS revealed a picture of human error within the R.O.C. Air Force. For instance, the data indicate that skill-based errors (42.6%) was those most frequently committed by pilots, followed by decision errors (41.8%), resource management (34.9%), adverse mental states such as stress, workload, and loss of situation awareness (33.7), violations (29.7%), poor crew resource management (27.6%), and perceptual errors (21.2%). The finding that the unsafe acts of operators accounted for the majority of causal factors was anticipated by the HFACS. However, the preconditions for unsafe acts were no less important

(Table 1). Adverse mental states, crew resource management, physical/mental limitation (13.9%), and physical environment (12.7%) combine to make up a high percentage of HFACS.

Table 1: Frequency and percentage of accidents associated with each HFACS Category

HFACS Category	Frequency	Percentage
Organizational Influence		
Resource Management	181	34.9%
Organizational Climate	4	0.8%
Organizational Process	76	14.6%
Unsafe Supervision		
Inadequate Supervision	175	33.7%
Plan Inappropriate Operation	24	4.6%
Fail to Correct Problems	12	2.3%
Supervision Violations	8	1.5%
Precondition for Unsafe Acts		
Adverse Metal States	180	34.7%
Adverse Physiological States	2	0.4%
Physical/Mental Limitations	72	13.9%
Crew Resource Management	143	27.6%
Personal Readiness	29	5.6%
Physical Environment	66	12.7%
Technological Environment	40	7.7%
Unsafe Acts of Operators		
Decision Errors	217	41.8%
Skill Errors	221	42.6%
Perceptual Errors	110	21.2%
Violations	154	29.7%

(The percentages will not add up to 100% because each accident is associated with multiple causal factors across HFACS categories.)

The categories of accidents (Table 2) showed that the distribution of major accidents was 207 (39.9%), minor accidents 75 (14.5%), and incidents 237 (45.7%). It should be note that major accidents were associated with missions of air combat tactics, air combat maneuver, and formation. However, minor accidents were associated with surface attack, instrument and solo flight.

Table 2: Categories of accident

	Observed N	Expected N	Residual
(Major Accidents)A	207	173.0	34.0
(Minor Accidents)B	75	173.0	-98.0
(Incidents) C	237	173.0	64.0
Total	519		

The accidents occurring during each phase of flight (Table 3) show that the most frequently committed human errors are at the stage of cruise/operational area 179 (34.5%), followed by landing 119 (22.9%), and take-off 72 (13.9%).

Table 3: Accidents happened during flight phase

	Observed N	Expected N	Residual
1.Taxi before Take-off	38 (7.3%)	64.1	-26.1
2.Take-off	72 (13.9%)	64.1	7.9
3.Climb-off	26 (5.0%)	64.1	-38.1
4.Cruise/operational area	179 (34.5%)	64.1	114.9
5.Descending	9 (1.7%)	64.1	-55.1
6.Approaching	36 (6.9%)	64.1	-28.1
7.Landing	119 (22.9%)	64.1	54.9
8.Taxi after Landing	34 (6.6%)	64.1	-30.1
Total	513 (6 missing data)		

The accidents happened during operational missions (Table 4) show that the most frequently committed human errors are at the stage of air combat tactics 100 (19.3%), followed by air combat maneuver 90 (17.3%), and night flight/instrument 70 (13.5%).

Table 4: Accidents happened during mission

	Observed N	Expected N	Residual
1. Air Combat Maneuver	90 (17.3%)	55.1	34.9
2. Surface Attack	52 (10.0%)	55.1	-3.1
3. Night Flight /Instrument	70 (13.5%)	55.1	14.9
4. Transition	45 (8.7%)	55.1	-10.1
5. Test Flight	36 (6.9%)	55.1	-19.1
6. Air Combat Tactics	100 (19.3%)	55.1	44.9
7. Formation	38 (7.3%)	55.1	-17.1
8. Solo Flight	32 (6.2%)	55.1	-23.1
9. Others	33 (6.4%)	55.1	-22.1
Total	512 (7 missing data)		

The overall Chi-square test (Table 5) shows that there were significant differences between the observed and expected frequencies by accidents category (χ^2 = 85.9, df =2, p<.001), mission (χ^2 = 95.2, df =8, p<.001) and phase of flight (χ^2 = 360.9, df =7, p<.001).

Table 5: Chi-square of categories of accidents, accidents happened during mission, and accidents happened during flight phase

	Categories of accident	Accident happened during mission	Accident happened during phase of flight
Chi-Square	85.873	95.206	360.903
df	2	8	7
Asymp. Sig.	.000	.000	.000

Discussion

At the level of 'unsafe acts by operators', skill-based errors were associated with the highest percentage of accidents (42.6%), including inadvertent use flight control, poor technique, negative habit and distraction. Decision errors constituted the second highest proportion (41.8%) including inappropriate maneuver, inadequate knowledge, exceeded ability, and wrong respond to emergency. Violations associated with breaking rules, regulations and standard operating procedures made up 29.7% of errors.

At the 'precondition for unsafe acts' level, adverse mental states contributed the highest percentage toward accidents (34.7%) including loss situation awareness, stress, overconfidence, task saturation, and mental fatigue. Poor crew resource management contributed the second highest percentage of accidents (27.6%) including lack of teamwork, failure of leadership, poor communication, mis-interpretation of calls, and inadequate brief. It should be noted that physical environment (12.7%) was associated with birds strike and foreign objects damage (FOD).

At the 'unsafe supervision' level, inadequate supervision was the largest proportion (33.7%), including; failed to provide proper training and professional guidance, failure to track qualification and performance, untrained supervisor, and loss of supervisory situational awareness.

At the 'organizational influence' level, resource management contributed the highest rate of accidents (34.9%), including human resources (selection, training, & staffing), monetary resources (cost cutting & lack of funding), and equipment resources (poor aircraft design, offering unsuitable equipment, & failure to correct known design flaws).

The highest accident rate during the flight phase was cruise/operational area, followed by landing and take-off (Figure 1). For military pilots the most dangerous tactical maneuver and training is always arranged within a specific operational area to avoid potential air misses with other fighters or civil aircraft. At this flight phase, pilots doing the most dangerous maneuvers need the highest requirements of physical and mental abilities in the cockpit. As a result, tactical maneuvering has the highest accident rate compared with other flight phases. It should also be noted that landing has the second highest rate of accidents and the same as the phase of operational area, accidents are usually major ones rather than minor accidents or incidents. The reason for this is that military fighters are loaded with external fuel tanks and weapons, and if something goes wrong, then the worst result can be anticipated.

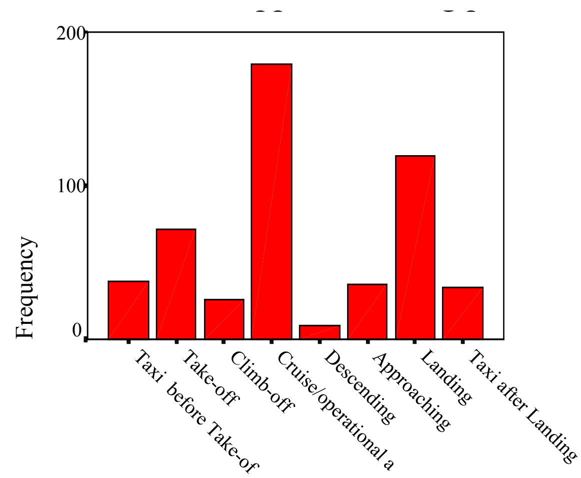

Figure 1: Accidents happened during phase of flight, the most frequent are Cruise/operational area, Landing, and Take-off.

The highest rate of accidents during operational missions occur during air combat tactics (ACTS), followed by air combat maneuver (ACM) and night flight/instrument (Figure 2). The mission of ACTS is associated with perceptual ability, motor skill and decision-making and pilots must be able to maintain situation awareness under high G-force environments to avoid the possibility of a ground or midair crash. As the result, ACTS has the highest rate of human error involved. ACM is similar with ACTS and is often used for the air-to-air combat mission, which is highlighted by the 'aircraft maneuvering engagement' (dogfight). Night flight/Instrument easily induces perceptual errors, loss of situation awareness, and skill-based errors, has and leads to a high percentage of accidents.

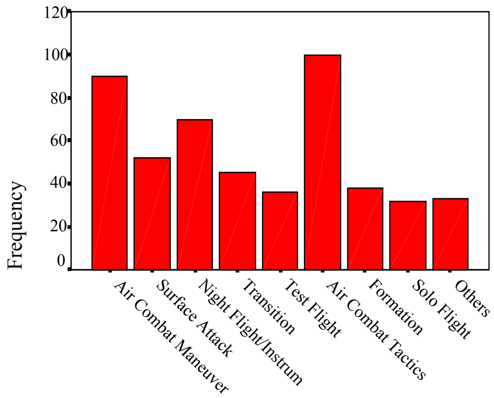

Figure 2: Accidents happening during missions: the most frequent are Air Combat Tactics, Air Combat Maneuver, and Night Flight/ Instrument.

Conclusion

The HFACS framework was found to categorize 1714 causal factors associated with the 519 accidents in the Air Force across 25-years. This finding suggests that the HFACS originally developed for use in the U.S.A. military, is also applicable for R.O.C. Air Force. Some error categories (e.g., Adverse Physiological States, Organizational Climate, and Supervisory Violation) are relatively scarce compared with decision errors or skill-based errors. One explanation for the scarcity of (occurrences in) such categories could be contrary to Reason's model of latent and active failures which HFACS is based upon. Such supervisory and organizational factors do not play a significant role in the R.O.C. Air Force. Another explanation, however, is that the differences are due to the organizational and cultural difference between U.S.A. and R.O.C. military aviation.

Human error is systematically connected to features of aircraft instruments and to the tasks of the operators and, as has been recognized more recently, their operational and organizational environment (Dekker, 2001). According to the findings of this investigation some particular types of fighters (e.g., F-104 & F-5E) and missions (e.g., Air Combat Tactics, Air Combat Maneuver, & Instrument) accounted for a very high percentage of accidents. The most important issue of human factors research is to understand why people do what they do. Only then can we change the world in which they work and shape their assessments and actions accordingly.

The violations such as breaking rules or taking short-cuts in procedures, are often induced by situations that reinforce unsafe acts and punish safe acts (e.g., emergent intercept mission). According to Reason's model of active and latent failures (1990), such violation-inducing situations are often set up by supervisory and command level decisions.

The CRM failures and decision errors are associated with a large percentage (69.4%) of aircrew-related accidents. Even though the Air Force Headquarters have already invested much effort to improve CRM and recognize the importance of aeronautical decision-making (ADM), it apparently has had little effect and needs further intervention and research.

Acknowledgments

This study was supported by the R.O.C. National Science Council (NSC-89-2212-E-013-001) and by Cranfield University for the presentation of this paper. We thank all pilots who participated and contributed their expertise and knowledge to help this research.

References

Dekker, S. (2002), *The Field Guide to Human Error Investigations,* Ashgate, Aldershot, England.

Dekker, S. and Woods, D. (1999), 'Automation and Its Impact on Human Cognition', in Dekker, S. and Hollnagel, E. (Editor), *Coping with Computers in the Cockpit*, Ashgate, Aldershot, England, pp. 7-27.

Dekker, S.W.A. (2001), 'The Re-invention of Human Error', *Human Factors and Aerospace Safety,* Vol. 1, pp. 247-266.

Diehl, A. (1991), 'The Effectiveness of Training Programs for Preventing Aircrew Error ', in Jensen, R.S. (Editor), *Sixth International Symposium on Aviation Psychology,* Vol. 2, Columbus, Ohio, U.S.A., The Ohio State University, pp. 640-655.

Diehl, A. (1989), 'Human Performance/System Safety Issues in Aircraft Accident Investigation and Prevention', in Jensen, R.S. (Editor), *Fifth International Symposium on Aviation Psychology,* Vol. 2, Columbus, , The Ohio State University, pp. 838-847.

Diehl, A. (1991), 'A Workshop on Understanding and Preventing Aircrew Error', in Jensen, R.S. (Editor), *Sixth International Symposium on Aviation Psychology,* Vol. 1, Columbus, The Ohio State University, pp. 28-39.

Feggetter, A.J. (1991), 'The Development of an Intelligent Human Factors Data Base as an Aid for the Investigation of Aircraft Accidents', in Jensen, R.S. (Editor), *Sixth International Symposium on Aviation Psychology,* Vol. 2, Columbus, Ohio, U.S.A., The Ohio State University, pp. 324-629.

Hollnagel, E. (1998), *Cognitive Reliability and Error Analysis Method,* Elsevier Science, Oxford, England.

Hunter, D.R. and Baker, R.M. (2000), 'Reducing Accidents among General Aviation Pilots through a National Aviation Safety Program', in Hayward, B.J. and Lowe, A.R. (Editor), *The Fourth Australian*

Aviation Psychology Symposium, Vol. 1, Ashgate, Aldershot, England.

Jensen, R.S. (1997), ' The Boundaries of Aviation Psychology, Human Factors, Aeronautical Decision Making, Situation Awareness, and Crew Resource Management', *The International Journal of Aviation Psychology,* Vol. 7, No. 4, pp. 259-268.

Johnston, N. (1991), 'Organizational Factors in Human Factors Accident Investigation', in Jensen, R.S. (Editor), *Sixth International Symposium on Aviation Psychology,* Vol. 2, Columbus, Ohio, U.S.A., The Ohio State University, pp. 668-673.

Klein, G. (2000), 'Analysis of Situation Awareness from Critical Incident Reports', in Endsley, M.R. and Garland, D.J. (Editor), *Situation Awareness Analysis and Measurement*, Lawrence Erlbaum , London, pp. 51-71.

McLucas, A.C. (2003), Decision Making: Risk Management, Systems Thinking and Situation Awareness, Argos, Canberra, Australia.

Orasanu, J., Davison, J., and Fischer, U. (2001), 'The Role of Risk in Aviation Decision Making: How Pilots Perceive and Manage Flight Risks', *Proceedings of the Human Factors and Ergonomics Society 45th Annual Meeting,* Vol. 1, Upper Midwest Chapter, Minneapolis/St. Paul, Minnesota, Human Factors and Ergonomics Society, Santa Monica, USA, pp. 58-62.

Reason, J. (1990), *Human Error,* Cambridge University, New York.

Shappell, S.A. and Wiegmann, D.A. (2001), 'Applying Reason: the human factors analysis and classification system (HFACS)', *Human Factors and Aerospace Safety,* Vol. 1, No. 1, pp. 59-86.

Strauch, B. (2002), Investigation Human Error: Incidents, Accidents, and Complex Systems, Ashgate, Aldershot.

Wiegmann, D. and Shappell, S. (1995), 'Human Factors in U.S. Naval Aviation Mishaps: An Information Processing Approach', in Jensen, R.S. and Rakovan, L.A. (Editor), *Eighth International Symposium on Aviation Psychology,* Vol. 2, Columbus, Ohio, U.S.A., The Ohio State University, pp. 1295-1299.

Wiegmann, D.A. and Shappell, S.A. (2001), 'Applying the Human Factors Analysis and Classification System to the Analysis of Commerical Aviation Accident Data', in Jensen, R.S. (Editor), *Eleventh International Symposium on Aviation Psychology,* Columbus, Ohio, The Ohio State University,

Wiegmann, D.A. and Shappell, S.A. (2003), A Human Error Approach to Aviation Accident Analysis: The Human Factors Analysis and Classification System, Ashgate, Aldershot, England.

Wiegmann, D.A. and Shappell, S.A. (2001), 'Human Error Perspectives in Aviation', *The International Journal of Aviation Psychology,* Vol. 11, No. 4, pp. 341-357.

Wiegmann, D.A. and Shappell, S.A. (1997), 'Human Factors Analysis of Postaccident Data: Applying Theoretical Taxonomies of Human Error', *The International Journal of Aviation Psychology,* Vol. 7, pp. 67-81.

Wiggins, M.W. and Stevens, C. (1999), *Aviation Social Science: Research Methods in Practice,* Ashgate, Aldershot